College-readiness in Science

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Executive Summary

Researchers who study students' transition to post-secondary education have cited a "disconnect" between the instruction provided to students in grades K–12 and what post-secondary educators believe students need to know and be able to do in order to be successful in college (Kirst and Venezia, 2001; 2004; Conley, 2007). International tests such as PISA reinforce this disconnect in the documentation of American students' underperformance on complex reasoning in science. Research suggests that more purposefully aligning K–12 educational standards with the expectations of higher education is a critical first step to bridging this gap. Subsequently, curriculum, assessment, professional development, teacher training programs, policy and advocacy efforts must be designed based on these standards.

As this paper will show, states need purposefully targeted standards that are deliberately aligned with expectations for entrance into college science courses. These standards should include performance expectations that specify how content knowledge is to be used and developed through reasoning and in problem solving. Until acted upon, *standards are only words on paper.* In order for real curriculum, assessment, professional development, teacher training programs, policy and advocacy efforts reform to take place, states and school districts must be able to translate the standards effectively. This translation poses one of the greatest anticipated hurdles in the current standards movement. As a solution, this paper suggests that a deep level of specificity in the integration of what students should know and how they should engage with the content will provide sufficient guidance for curriculum supervisors and teachers to design instruction and assessments at the K-12 level that prepare students for college courses.

Challenges in Defining College-Readiness

At the request of Achieve Inc., the College Board assembled a small team of researchers to study what is meant by the term "college-readiness" in the discipline of science. College-readiness continues to be an emerging concept, and it has been defined by a number of groups and researchers — each with a slightly different interpretation. The definition of college readiness most often used in standards documents is one where students are considered 'college-ready' when, "they have the knowledge, skills and abilities to successfully complete a college course of study without remediation" (College Board, 2007). The term "succeed" is often defined as, "completing introductory courses at a level of understanding and proficiency that makes it possible for students to consider taking the next course in the sequence or the next-level course in the subject area" (Conley, 2007).

While this definition of college-readiness is useful for many disciplines, it poses several unique problems when defining college-readiness for science. First, as a result of the decentralized education system in the United States, the disciplines of science (e.g., life, physical, earth, etc.) that are taught at the K-12 level vary widely in sequence and in content coverage depending on state, district, and even school. Second, very few colleges or universities have remedial classes for science. Students are usually enrolled in the same freshman level science course whether they need remediation or not. Without remedial courses in science, it is difficult to use the definition above as a measuring stick for college-readiness. Third, a wide variety of colleges and universities exist in this country, giving rise to a tremendous disparity of expectation regarding student graduation requirements in science. This reality makes using the aforementioned definition an unreliable measure of how well a student is prepared to enter a college level science course as it may be possible for a student to succeed at one college but not another. In addition, some schools require students majoring in science to take "more advanced" science courses than the non-science majors while other schools simply require all students to complete the same level of courses with the expectation that science majors take additional or higher level courses as they progress though the program. Other colleges only require very low-level or non-sequential science courses for non-science majors. It is for these reasons that a more descriptive definition of what it means for a student to be "college-ready" in science is needed to support how one might approach developing a national science standards document.

Background and Context

A number of organizations and frameworks have made significant contributions to refining the way we think about the end-goal of a science education, and in order to support a new definition for college-readiness in science some background and context must be studied first. The work that has been done to this point will help to provide a clearer understanding of current students' classroom experiences with science and lend insight into where critical gaps exist between K–12 expectations for science learning and what is needed for success in higher education. In addition, the description of the evolution of the standards movement underscores the need for greater specificity in how the standards connect back to the curriculum, assessment and professional development that they are suppose to drive.

To start, evidence-based college-readiness standards development is an emerging trend in educational reform. International comparisons of standards and the correlations between standards and assessments, such as PISA and TIMSS, have been the grounds of much debate within the educational research community, especially when used to inform policy decisions about college-readiness and international competitiveness (Cavanagh, 2009). Until recently in the United States, standards reform was most often driven at the state level, resulting in a patchwork of fifty state standards all varying in terms of content, scope, depth, and breadth. As a consequence, educators are presented with inconsistent and sometimes contradictory learning goals. Some state standards frameworks establish the goal of general academic literacy in a discipline, while other frameworks focus specifically on college preparation or career-readiness skills. Additionally, national professional organizations have created their own discipline-specific standards.

In contemporary educational discourse, the term "standard" is used to refer to several different things. Content standards generally specify what students should know and be able to do as a result of instruction in a subject area. They describe the concepts and skills that students are expected to master at a particular point in their education. The purpose of content standards is to guide instruction by focusing educators on a specific set of topics that represents the goals of the authoring body — often state decision-makers or committees established by professional disciplinary societies. Performance standards, which under No Child Left Behind (NCLB) are also called achievement standards, describe what is expected of students regarding their level of proficiency or mastery as measured by state or district assessments. When policymakers and the public call for higher educational standards, they often use the term to refer to an entity that includes both of these types of standards (College Board, 2009).

History of Standards

In the United States, the concept of educational standards has been evolving over the past 100 years, with particular acceleration in the last 30 years. There have been many significant points in this evolution, beginning with the NRC's 1983 landmark report, A Nation at Risk, which calls for higher "standards" in the five new basics of science, mathematics, English, social studies, and computer science (plus a foreign language for college-bound students). Although this report certainly was not the first to call for standards reform, it was the first to link accountability to student assessment. Within months of the NRC report, the National Science Board came out with a report of its own, titled Educating Americans for the 21st Century. This report lists the essential topics students should know in the various science fields. Then, in 1989, in order to ensure that the United States would remain internationally competitive, the newly elected president, George H.W. Bush, along with the governors of each state, agreed to establish clear national performance goals and strategies for K- 12 education. After much debate, it was also agreed that each state should give an annual report on its progress in meeting those goals.

Later in 1989, the American Association for the Advancement of Science (AAAS) Project 2061 published Science for All Americans, which outlines a vision of science literacy for all and lays out, in detail, what all citizens should know in science. This publication cleared the way for several other publications by AAAS that were focused on education. In 1993, they published Benchmarks for Science Literacy, which outlines what students would have to learn by the end of four grade bands to achieve the goal of science literacy for all. In 2001, after the Improving America's Schools Act (1994), the re-authorization of the Elementary and Secondary Education Act of 1965 which required states to develop challenging content standards describing what students should know in mathematics and language arts, AAAS Project 2061 began working on their Atlas of Science Literacy. AAAS undertook this project partly because the NRC had failed to gain much traction in their 1996 attempt to create a national science standards document and partly because the No Child Left Behind Act (NCLB) was being debated. Ultimately, NCLB significantly increased testing in math and language arts and added stiffer sanctions for failure to meet performance goals; however, it failed to include science assessments until 2007. In 2007, AAAS Project 2061 published volumes one and two of Atlas of Science Literacy, which outlined a logical sequence by which science ideas should be learned (previously outlined in the publication Benchmarks for Science Literacy).

In September 2009, the College Board published the Science College Board Standards for College Success (SCBSCS). The College Board is part of a transition to a new generation of standards in ELA, mathematics and science, and this work draws heavily on many of the publications outlined above. In order to articulate how students would use their knowledge, the College Board document contains performance expectations in which science practices and content are well integrated. The SCBSCS thoughtfully outlines a vertical integration, with college readiness as the primary target (as operationalized in the redesigned Advanced

Placement® [AP] curriculum), with logical progressions between middle and high school, and then to AP (i.e., college readiness). Due to the limited data available at the time of this publication to support complete learning progression standards, the SCBSCS committee used the research available for guidance when developing the pathways to college readiness. When the research was not available, the distribution of expertise among the committee's middle school and high school teachers, college faculty and learning specialists identified relevant experiences to further support the pathway's development.

In order to ensure alignment to the selection of the knowledge, skills and abilities that are needed for success in entry-level science courses, the College Board sponsored a survey of 146 post-secondary institutions that defined the knowledge, skills and abilities their faculty members believed were critical to success in first-year college courses (Conley, et al., 2005). Data were collected from 171 additional post-secondary institutions, and the knowledge, skills and abilities necessary for successful performance in entry-level college courses were identified (Conley, et al., 2006). The definitions of college readiness gathered through these surveys, course analyses and case studies represent a well-researched, empirically-validated definition of college readiness (College Board, 2009).

Creating a Better Definition of College Readiness

It is important to distinguish between college readiness and scientific literacy. Our research suggests that what makes a student college-ready can be defined more precisely than what makes a student scientifically literate (College Board, 2007). The College Board views scientific literacy as a spectrum and has established a benchmark along that spectrum that defines college readiness; a student's literacy can be defined as either more-developed or less-developed along that spectrum, but it is impossible to say that a student is, or is not, scientifically literate. Defining the end goal for the Standards in this way allows for a greater focus on the knowledge, skills and abilities that students need for success in first-year college courses.

Of course, creating a more "precise" definition of college-readiness in science can also pose significant problems. For example, as discussed previously, different colleges have different expectations and admission requirements, and it would be impossible to get all universities to agree on a single definition. Nevertheless, our K-12 education system must align with an end-goal benchmark in order for students to progress through a K-12 system that will prepare them for higher education, regardless of which college they attend. While the level of this benchmark is difficult to place, its importance cannot be overstated. First, the end-goal should not cater to the lowest common denominator nor apply solely to the top echelon of students. Second, the end goal should not be arbitrarily set. In order to validate something as broad as college-readiness, the definition must take into account the voices of several (often competing) stakeholders. Most of these stakeholders have valid opinions about what should or should not be included in such a definition, and it would be wrong to simply dismiss these opinions without clear evidence and research. Benchmarks for cognitive levels and understandings are better developed in young childhood education, sparked by the seminal work of Piaget. Ages at which children should speak, walk, and read are supported by scientific research, whereas goal cognitive levels and skills of eighteen year olds are more philosophical, political, and subjective. Different frameworks which have been outlined by states, universities, federal government, society, culture, philosophers and experts in the field highlight the different ideals of where students should be when they enter college. Because of this, education standards do not set the bar of college readiness; rather, they should reflect the bar that has been set by these ideals.

More research is needed to bring together these ideals in an effort to better define a level of college readiness. While these frameworks embody different values, priorities, and goals, research can be done to eliminate moot points and reach greatest consensus regarding the level of college readiness. While we do not set the bar of college readiness in this paper, we do determine categories of knowledge needed for college readiness and offer suggestions for future research.

Purpose of this Paper

With this history and research in mind, this paper chiefly focuses on what students must know and be able to do in order to be college-ready. Furthermore, it discusses supports needed for students to reach these goals. Three knowledge categories were identified as necessary for a student to be college ready in science. In order for a student to be college-ready in science he or she must:

(1) have knowledge of the overarching ideas in the science disciplines (i.e., earth and space science, life science, physical science, and engineering) and how the practices of science are situated within this content;

(2) have a rich understanding of the nature and epistemology of science, scientific discourse, and the integration of science, technology, and society;

(3) have metacognitive skills and self-efficacy related to the practices of science.

This paper describes the underlying structure, components, and facilitation of these broad categories, whereas specific learning goals are embedded in the Next Generation Science Framework. By providing an overarching view of these categories, this paper seeks to give context to the Science Framework and aid in the translation of standards to policy, curriculum, assessment, and professional development.

In addition to *what* students should know, this paper discusses *how* to facilitate the development of this knowledge. In order for students to reach college readiness, major stakeholders (i.e., policy makers, administrators, educators, parents) are held accountable for facilitating outcomes 1-3 by:

(4) providing learning environments that foster positive attitudes towards science

(5) holding students to an equitable outcome; and

(6) providing students with a coherent pathway of science education from K-12.

What students should know (items 1-3) and *how* students should be supported (items 4-6) are equally valuable pillars that together define college readiness. Students cannot achieve college readiness without the supports of items 4-6, nor can they be college ready without any one of items 1-3. The remainder of this paper explores these six guiding principles, research to date, and how these principles prepare a student for college science work. Each section includes implications regarding policy, curriculum, assessment, and professional development in an effort to better enable all students to reach college readiness.

Ideas in Science and Integration of Science Practices

Central to science is the goal of establishing lines of evidence and using that evidence to develop and refine testable explanations and make predictions about natural phenomena. Standards documents must reflect this goal of science by focusing on developing, in all students, the competencies necessary for constructing testable, evidence-based explanations and predictions. In the course of learning to construct testable explanations and predictions, students will have opportunities to identify assumptions, to use critical thinking, to engage in problem solving, to determine what constitutes evidence, and to consider alternative explanations of observations. An important goal of school science is to help students understand how explanations about one part of a system might be applied to thinking about new, or less familiar, problems and situations (College Board, 2009).

Competence in science requires the integration of knowledge about how the natural world works with an understanding of how that knowledge was established, extended and refined, and how it can be used in both familiar and more novel situations. Standards must outline a clearly defined "skills" section, or "science practice" section, to describe the ways in which students are expected to apply and deepen their conceptual understanding of discipline-specific content knowledge through engagement in the types of "practices" that scientists use to accomplish a goal or to complete a task. The practices described are not discrete skills, but rather a rich set of integrated ways of thinking that support the development of conceptual understanding of science concepts, develop the habits of mind that are necessary for scientific thinking, and allow students to engage in science in ways that are similar to those used by scientists.

While the Next Generation Science Standards Framework will outline the specific practices to be included in the final document, it is important to note that the science practices are deeply interconnected and nonlinear. For example, scientists do not always begin with a well-formulated scientific question. Sometimes, following careful observation over a period of time, patterns become apparent in the observed phenomena, prompting the scientist to ask specific empirically-testable scientific questions (College Board, 2009). These scientific questions are stated, revised and then restated. It is important to note that these practices are almost always iterative, and it is this iterative approach that allows students to practice science in an authentic way. Competence in science requires the application and integration of content knowledge, experimental and mathematical procedures, and symbolic representations in order to interpret situations and solve scientific problems. Students should be expected to apply their science content knowledge by engaging in the following practices that are similar to those used by scientists in their work and reflect the authentic, iterative and dynamic nature of science (College Board, 2009):

- Capture the aspects of science reasoning that are necessary for building, justifying and evaluating evidenced-based, testable explanations and predictions
- Represent multiple ways of "knowing science" in order to better understand the natural world; allow teachers and students to engage in practices that are used by scientists in different science disciplines
- By focusing on science practices related to the development of evidence-based explanations, teachers can address other important aspects of science learning, such as revising students' alternative conceptions about natural phenomena, developing their modeling skills, and promoting conceptual change

- Science practices must be taught and learned within the context of discipline-specific science content; therefore, the use of science practices promotes the integration of content knowledge and skills

When students engage with these practices in an authentic way, they begin to build a deep understanding of how the disciplines of science are a way of viewing the world. It is this scientific epistemology that prepares students for college.

Through the development of these integrated practices within the content of each discipline (i.e., earth and space science, life science, physical science, and engineering), students will come to understand the overarching principles and core ideas that have explanatory power within and across science disciplines; these are know as the "Unifying Concepts" or the "Cross-Cutting Themes" of science. This level of understanding can be achieved when students focus on specific integrations of practice and content (often referred to as performance expectations) that describe ways in which they are expected to use and build their science understanding to accomplish a goal or task. By including a unique set of science practices that focus on developing the competencies necessary for engaging in scientific discourse and constructing evidence-based explanations and predictions, the document can offer a level of specificity which will provide sufficient guidance for both curriculum supervisors and teachers as they design curriculum, instruction and assessments that prepare students for college-level science courses.

Nature and Epistemology of Science, Scientific Discourse, and Science Technology and Society

Children naturally develop and engage in knowledge-seeking practices, including some of the practices implemented by scientists. However, students must be able to distinguish the epistemology of science from other ways of knowing in order to practice science and to assess the benefits, applications, and limitations of this form of knowledge. For instance, students should consider questions such as: How is a hypothesis tested? What counts as evidence? How is scientific knowledge constructed? In addition, it is import that students understand the relation of science to technology and society, for instance, how science contributes to the development of technology and vice versa, and how societal conditions can influence the direction of scientific inquiry. In order to be college-ready, students should have an explicit understanding about how the epistemology of science allows for a way of interpreting the natural environment.

Children are innately curious and attempt to make sense of the world around them (NRC, 2011). Children's minds are not blank slates to be filled with knowledge (Redish, 1994). Rather, they enter the classroom with a "great deal of knowledge" about the world around them formed from their everyday experience (Hammer, 2000, p. S53). Cognitive studies show that children organize their knowledge into mental models describing how the world works (Redish, 1994). When a student knows little about a topic, combining new information with his or her existing knowledge is relatively easy. This process is what Posner et al (1982) refer to as "assimilation." However, a child's mental models or conceptions about the world may contain contradictions and may be incorrect; how to address these misconceptions continues to be hotly debated in educational research. Nevertheless, the misconceptions or alternative models children have must be considered in science education since researchers agree that changing these mental models is very difficult (Redish, 1994). Posner et al (1982) argue that this process of conceptual change or "accommodation" requires that four conditions be fulfilled. First, a child must experience dissatisfaction with current conceptions. Second, the new concept must be intelligible to the child. Third, that concept must be plausible (i.e., the child must be able to see how it can be applied). Finally, the new concept must appear fruitful, meaning that it must have some explanatory power for the child. These researchers argue that conceptual change, although difficult, is achievable given the right conditions. Pintrich, Marx, and Boyle (1993) add to this finding, noting that conceptual change is not an isolated process but that it is influenced by personal, motivational, social, and historical factors. In this way, they argue for a more holistic approach to the process of conceptual change, taking into account factors such as student motivation. Other researchers suggest that, rather than focusing on changing students' misconceptions, it is more effective to use correct aspects of students' mental models, or what Hammer refers to as intellectual "resources" (Hammer, 2000, p. S53), to help students learn scientific concepts. While researchers disagree about the most effective way to address student misconceptions, consensus exists that these persistent misconceptions can pose a significant hurtle for students learning science at all levels (Hammer, 2000).

In developing mental models and making sense of the world around them, children draw from multiple ways of knowing. Hammer and Elby describe examples of children's epistemologies – knowledge as made-up, knowledge as inferred, and knowledge as inherent (2002). In addition, children invoke different epistemologies in different contexts (Hammer and Elby, 2002). For example, a child may draw from intuition when considering faith-based ideas yet use deterministic reasoning when in the science classroom. To help children learn science, Hammer and Elby suggest eliciting and building upon children's pre-existing epistemological resources that are productive to learning science (2002).

Underlying children's mental models and epistemologies are their worldviews. Cobern (1994) explains, "worldview provides a person with presuppositions about what the world is really like and what constitutes valid and important knowledge about the world" (p. 5). In other words, a child's worldview determines what is to be learned. In order for a child to learn science, he or she must have a "scientifically compatible worldview" (Cobern, 1994, p. 5). Otherwise, the student will see learning science as unimportant, not useful, and irrelevant to his or her life and identity. A scientifically incompatible worldview prevents students from constructing scientific knowledge in meaningful ways.

The purpose of discussing children's natural ways of constructing knowledge is to emphasize the importance of learning the epistemology and nature of science and to highlight the care necessary to convey these ideas. Children already construct meaning from their lived experiences, and they should learn science as another way of knowing with its own epistemology and underlying assumptions. The following paragraphs describe what students need to know about the epistemology of science in order to understand and participate in science on a college level.

First, students should know that science is one of many ways of knowing. Science is not a superior way of knowing -- there is no universal epistemological hierarchy, rather certain ways of knowing are more appropriate in certain contexts for certain people. Scientific knowledge is socially constructed based on inferences from the environment in which we live. While science attempts to model reality, it is not itself reality. Johnson explains, "there is no way to know whether science is converging on a single truth, the way the universe really is, or simply building artificial structures, tools that allow us to predict, to extend, and to explain and control" (1995, p. 6). This should not downplay the value and utility of scientific knowledge. Students must be shown how scientific discoveries have led to huge advancements in healthcare, food production, transportation, and communication, and how the application of scientific knowledge affects them everyday. At the same time, students should explore how the application of scientific knowledge has also led to environmental destruction and energy controversy. Science as a way of knowing presents great possibilities for the human race, but like any other kind of knowledge, can have both positive and negative consequences. It is important that this dichotomy is presented to students as it helps facilitate students' engagement in science and highlights that science is not doctrine.

Second, students should understand the role of data and evidence in constructing scientific knowledge. Scientists can test hypotheses by performing experiments to investigate phenomenon. They design experiments that highlight the effect of one variable and attempt to control other variables in order to minimize their impact on the phenomenon being observed. Scientists make observations and collect data that describe the effect of the variable on the phenomenon being investigated. They carefully decide what data to collect so that their data can be used as evidence to disprove or fail to disprove their hypothesis. They perform multiple trials and attempt to minimize bias in order to make their evidence stronger. One should note that while data may serve as evidence in support of a hypothesis, a hypothesis can never be proved since infinitely more experiments could be performed where the results may differ. The ability to understand the role of data and evidence in constructing scientific knowledge must be scaffolded from a very early age and explicitly integrated into standards, curriculum, assessments and professional development in science education.

Third, science is often thought of as absolute, but students must be encouraged to think of science as a way of knowing and not a way of arriving at a set of conclusive answers. Lederman (2006) notes that many teachers and scientists believe scientific knowledge is absolute as well. In a study of nearly 1000 science teachers and 300 practicing scientist Behnke (1961), found that over 50 percent of science teachers and 20 percent of scientists think that scientific findings are certain. Lederman (2006) notes the importance for students to understand how, "[s]cientific claims change as new evidence, made possible through advances in theory or technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs" (p. 834). This aspect of the epistemology of science may be difficult to convey in lecture-based courses where knowledge comes from authority (i.e. the teacher) and is stated as fact, but must be addressed if students are to build a deeper understanding of science as a way of knowing.

A fourth critical element of learning scientific concepts and the epistemology and nature of science is the role of scientific discourse. Science is a communal activity. All scientists must share their explanations and predictions with other scientists so that these explanations and predictions can be subjected to further empirical testing, analysis and refinement. Thus, the entire scientific endeavor rests on discourse. Scientists must be adept at interpreting the communication of others and at communicating the results of their own work to the larger scientific community in ways that will be understood and valued. Scientific knowledge becomes validated through presentation, argumentation, and consensus of practitioners. After a scientist collects data in support of or against a hypothesis, he or she may present his or her findings at a conference of practitioners or in a paper to be peer reviewed and published. This process of validation often involves argumentation, collaboration, and sometimes more experimentation until a consensus is reached. Nevertheless, some scientists may continue to disagree. Scientific findings attempt to describe reality, and multiple ideas may circulate at any given time.

For this reason, students must engage in scientific discourse for the purposes of collaboration and communication. One should note that discourse is a cultural process that must be taught explicitly, especially in multicultural settings. Education researchers offer several avenues to engage diverse populations in scientific discourse. Brown (2006) suggests helping students develop scientific concepts in vernacular language and making explicit switches to scientific language. Emdin (2010) suggests allowing urban youth to use types of communication they engage in outside of the classroom to demonstrate science learning in the classroom. Regardless of method, discourse in the science classroom is a crucial component of engaging students and building their understanding of the epistemology of science.

Fifth, students should know how scientific knowledge differs from other forms of knowledge. Students have access to an overwhelming amount of information, most of which is presented from a number of viewpoints constructed using multiple epistemologies. Students must be equipped with multiple ways of filtering this information and know when to apply the appropriate filter. For example, historical and cultural studies of the environment may show different aspects of human impact as compared to findings gained from scientific studies. Knowledge from multiple disciplines is often complementary, yet students should know how scientific knowledge is distinct from other knowledge in order to apply it appropriately. In addition, with the growing amount of socially constructed knowledge on the Internet through sites such as Wikipedia, blogs, and Twitter, students should be able to distinguish how scientific ideas evolve into knowledge as compared to the evolution of ideas through social networking (DeBoer, 2009). Students of the 21st century have access to more knowledge than ever before, and they must be able to evaluate the legitimacy, benefits, and limitations of that knowledge in order to apply it. In this way, students can begin to develop a scientific epistemology that will drive the evaluation of the information that they encounter in their daily lives.

Sixth, students should understand the role of imagination and creativity in doing science. "Science involves the invention of explanations, and this requires a great deal of creativity by scientists" (Lederman, 2006, p. 834). In analyzing data and constructing theory, scientists must be able to imagine the possibilities of what their findings may signify. For example, before Galileo, many people could not imagine that the Earth circled the sun, and it was not until the 20th century with the work of Edwin Hubble that many people began to think of our solar system as a very small part of one of billions of galaxies. Human cognition poses a limit to the possibilities of scientific inquiry (Johnson, 1995), but with greater imagination data can be interpreted in multiple ways. Imagination and creativity open windows of possibility in scientific endeavors, and science education should help develop these capacities.

In addition to learning the epistemology, and practices of science, students should understand how the scientific endeavor is situated within larger society. A critical interdependence exists among science, technology and society. Students should recognize the importance of how the advancement of technology relies heavily on scientific knowledge and on the advancements of this knowledge, how technological progress informs scientific research, and how society is also integrated into this reciprocal relationship. Students should have the opportunity to use technology in the science classroom in order to help them develop their understandings. Science curriculum should present societal issues that have arisen as a result of science and technology as well as development in science and technology that resulted from society's demands. For example, the development of the World Wide Web has radically changed how societies communicate and share information, and increased human energy consumption has driven the development of cheaper and cleaner alternative forms of energy in order to address economic, environmental and socio-political issues. Building students' appreciation for the integration of science, technology and society is based on the problems and situations that they examine or experience both inside and outside of the classroom. Science curriculum should include real-world problems and situations that present students with opportunities to develop their understandings of the interdependence that exists wherever possible.

Cognitive Skills and Self-efficacy

Historically, much of the discourse around preparing students for college level science has focused on the content of preparatory courses like earth science, biology, chemistry, and physics. However, as the United States has declined internationally in comparative measures of science competency, that discourse has shifted to include the skills, attitudes and behaviors necessary for success in college. In 2009, The Program for International Student Assessment (PISA) found that the average score of students in the United States was lower than the average score of students in 18 other nations (NCES, 2000). Moreover, the National Science Foundation cites a decline in student enrollment in undergraduate engineering programs of almost 20 percent between 1983 and

1999 (Science and Engineering Indicators, 2002). This decline in enrollment is compounded by concerning evidence about student retention in science and engineering programs. While 25 to 30 percent of students entering college in the United States intend to major in science or engineering, fewer than 50 percent of those students complete a science or engineering degree within 5 years (NSF, 2002). This pattern is not exclusive to undergraduate programs in science and engineering, but extends to graduate science programs as well. Long term trends show that the enrollment of foreign graduate students in science and engineering in the United States is increasing, while, at the same time, U.S. student enrollment in these programs continues to decline (NSF, 2002). Faced with these trends, stakeholders have been forced to address what skills, attitudes, and behaviors are necessary for students to succeed at the college level and to be motivated to engage in science. Research in science education and cognition identifies several attitudes and behaviors related to student motivation and feelings of self-efficacy in science. These attitudes and behaviors, determined by researchers and educators to be critical to college preparedness, are addressed in this section.

Metacognition – Definitions and Implications for College Readiness

The first of these behaviors is metacognition, originally coined by John Flavell to mean "thinking about thinking" (1979). More broadly, metacognition encompasses monitoring, regulation, and evaluation of one's knowledge (Schraw & Moshman, 1995; Schraw et al, 2006). The ability of a student to monitor his learning and to think consciously about understanding as a process is a key component to college-level study. Kuhn (2000) partitions metacognition into declarative knowledge (i.e., knowing that), procedural knowledge (i.e., knowing how), and what Schraw et al (2006) refer to as conditional knowledge (i.e., knowing why and when to apply a given strategy). General consensus exists among researchers that metacognition develops over time with children as young as three referring to their own knowledge with terms such as "think" and "know" (Flavell, 1999). However, in recent years, focus has been placed on the importance of metacognition in both acquiring knowledge and in transfer of knowledge to new contexts, both crucial skills for college readiness. Kuhn and Pearsall (2000) further argue that scientific thinking is rooted in early metacognitive development.

Metacognition, which is initially externalized in social groups, as when students ask each other "how do you know?", "how did you get that answer?", or "what makes you say that?" becomes internalized over time, making students more likely to pose those questions to themselves (Kuhn & Dean, 2004). Vygotsky refers to this process as "internalization." Schraw and Moshman (1995) argue that peer collaboration can help students evaluate and refine their metacognitive theories, while Kuhn and Dean (2004) note that social discourse and resulting internalization of metacognitive processes have been associated with improvement in learning outcomes. The opportunity to practice metacognitive behaviors within the science classroom is especially relevant since the peer collaboration that fosters metacognition also mirrors the process of collaboration that scientists use to advance scientific understanding. Kuhn (2000) notes that monitoring and evaluation of cognition may not be fully realized until adulthood, if at all, but argues that students should be encouraged to reflect on their learning. With this in mind, it is crucial that students be provided with opportunities to utilize and develop metacognitive thinking. This can be achieved through implementation of both curricular structure and pedagogical practices that support the development of metacognition. Development of metacognitive thinking related to self-monitoring and regulation are among what Conley refers to as "academic behaviors" necessary for the success in college (2007).

Metacognitive skills are necessary for success, but what level of metacognition is needed for college readiness? The style of instruction, amount of individual work, and student accountability are different in K-12 education as compared to college courses. College students often listen to lectures and then use presented information to complete assignments. In order to do this, students must have an internal dialogue to help them understand the content. During a lecture students may ask themselves: What are the main ideas? Do I think this is true? How would this apply to a particular situation? Does this make sense to me? A student's internal dialogue may lead to questions asked during class or discussions with classmates. However, the level of metacognitive skill needed in college differs from college to college. Colleges do not explicitly state an expected level of metacognitive skill, but a close analysis of course structure, how students are taught, and assignments would provide insight on the level of skill required. To reach a more refined definition of college readiness, a sample population of colleges may be studied to identify common expectations. In addition, it should be mentioned that there is also a reform effort occurring in college science curriculums allowing for more discourse and the strategic and explicit continued development of metacognitive skills.

Once a bar is defined, how to measure metacognitive development in a child's progress through K-12 education must be considered to assure progress towards that goal. Metacognitive skills are not specifically measured in state assessments. Instead, metacognitive skills are necessary to learn and answer questions concerning what is being assessed. Metacognition is not measured in isolation, nor are metacognitive skills written as standards. Rather, metacognition is developed through pedagogical practices.

This directs the question of metacognitive development to teacher educators and has implications for what is learned in teacher preparation programs. More research is needed to determine the level of metacognition students should develop and supports needed to reach this goal.

Self-efficacy

While there are a number of external factors correlated with achievement in science, self-efficacy is a strong predictor of both achievement and engagement in science activities both inside and outside of the classroom (Kupermintz, 2002; Lan & Roeser, 2002). Britner and Pajares (2006) define self-efficacy in science as "students' belief in their ability to succeed in science tasks, courses, or activities" (p. 486). Bandura (1986) argues that self-efficacy beliefs are often better predictors of achievement than are objective assessments of students' abilities because they influence both behavioral and psychological processes. Britner and Pajares (2006) further note that students who feel confident that they can be successful at science tasks are more likely to take on such tasks and to persevere in completing them. They argue that the inverse is also true; students who lack a strong sense of self-efficacy in science are more likely to avoid science activities or to give up when faced with challenges (2006). With this in mind, students should be given opportunities to present their ideas, receive constructive feedback and to reflect on their own learning goals. These opportunities for reflection provide a context in which a student can evaluate his or her success in the science classroom. In this way, students may be encouraged to strengthen their self-efficacy beliefs. Multiple studies have shown that self-efficacy is a predictor of achievement at the middle school (Britner & Pajares, 2001; Pajares, Britner, & Valiente, 2000), high school (Kupermintz, 2002; Lau & Roeser, 2002), and college levels (Andrew, 1998). Therefore, educators who wish to facilitate student progress and motivation in science should be attentive to helping students build their self-efficacy beliefs in science.

Similar to metacognition, there are not specific supports to facilitate students' development of positive self-efficacy. Teacher education programs should emphasize the importance of self-efficacy and how to help students develop confidence in science. In addition, administrators can learn management techniques to help build self-efficacy. But for self-efficacy to be thought of as an important aspect of science education, it should be considered how to incorporate the goal of positive self-efficacy into science curriculum resources.

Fostering Positive Attitudes towards Science

While academic behaviors are salient to the discourse around college-readiness, success in science is not solely a result of having the necessary skills. Positive student attitudes toward science are critical to fostering student interest and engagement in the sciences in college and beyond. Much of what is suggested in science education research is that students hold generally positive attitudes about science and about the importance of science to society leading up to middle school, but that student interest in science seems to be eroded by "school science" at the secondary level (Kahle & Lakes, 1983 as cited in Osborne, Simon, & Collins, 2003). This suggests that the curriculum and pedagogy entrenched in most secondary school science is actually working against promoting positive attitudes and interest in science. In order to address college readiness in science, it is critical to acknowledge the negative attitudes that exist towards science and to establish conditions that foster positive attitudes among diverse student populations. While standards can only indirectly influence student attitudes, it is critical to keep these factors in mind because science standards will impact both curriculum and pedagogy.

Ample research has been done around gender differences in attitudes towards science. In multiple studies, boys have more positive attitudes towards science than girls, although the effect varies by subject with the gender effect on attitudes being stronger in physics than in biology (Weinburgh, 1995). Much of the research suggests that this is a result of the way in which girls and boys are socialized. As a result, students in secondary schools are more likely to be influenced by the normative expectations of their peers (Head, 1985). Whitehead (1996) found that males were more likely to gravitate towards gender-stereotyped careers than females and suggests that this reveals a greater need among boys to establish and strengthen gender identity than among girls. Osborne, Simon, and Collins (2003) conclude that, "for boys, doing science, a subject which both genders perceive as stereotypically male, and in the case of girls, not doing science, is a means of establishing one's own gendered identity" (p. 20). With this in mind, science educators should make a concerted effort to address these gender differences by helping all of their students to engage with the science curriculum in meaningful ways.

Another critical influence on students' attitudes towards science is the quality of their teacher's instruction and of the students' learning environment. Multiple studies confirm that these factors have a significant impact on students' attitudes and choice of subject matter. Druva and Anderson (1983) found that student outcomes were related to the science training of their teachers. This is significant in an educational climate where science teachers are often asked to teach outside of their content area. Myers and Fouts (1992) surveyed attitudes of 699 students from 27 schools and found that the most positive attitudes among students were associated with high levels of student involvement, teacher support, group affiliation, and innovative teaching within a structured environment. These findings are significant to the discussion around pedagogy. In order for teachers to create the conditions that foster positive student attitudes, they must be provided with the professional development and support necessary to develop effective pedagogical strategies. In a study by Ebenezer and Zoller (1993), 10th grade students emphasized that the teaching practice of their instructors was influential to their enjoyment and comprehension of science. Moreover, Haladyna, Olsen, and Shaughnessy (1982, 1983) indicate that characteristics like teacher praise and encouragement, and formality of the classroom can be manipulated to foster more positive attitudes towards science among students. Atwater, Wiggins, and Gardner (1995) concluded that these affective aspects of the classroom were more important to student attitudes than the physical environment of the classroom or the school. These findings have significant implications for both the structure of curriculum and for the delivery of science instruction. The literature around developing positive student attitudes towards science underscores the importance not only of teacher content knowledge but of the ability of teachers to use varied pedagogical strategies in their delivery of that knowledge.

Factors related to students' attitudes and behaviors must be taken into account as educators strive to keep students motivated and engaged in the sciences. In an era when science and technology are so engrained in American culture and in the lives of adolescents, it is alarming that fewer students are entering the field of science. This trend appears to begin at the middle and high school levels where a disconnect exists between students' appreciation of the value of science in society and their interest in studying science in school. In a 1993 study, Ebenezer and Zoller surveyed 1564 tenth grade students. Of the students surveyed, 72% responded that they think science is valuable and 73% indicated that science in schools is important, but almost 40% noted that they found science classes boring (1993). These studies are further substantiated by statistics from the 2007 NCES report, The Condition of Education. According to the National Center for Educational Statistics almost all students take one year of high school science (The Condition of Education, 2007). However, NCES (2007) reports that as of 2004, only 68 percent of high school graduates successfully completed a subsequent science course or second year of science. This report defines a second year of science as any course that is classified as more challenging than general biology (NCES, 2007). The percentage of graduates who had completed at least one course of either chemistry II, physics II, and/or advanced biology drops to just 18% (2007). Even fewer take Advanced Placement science courses (e.g. 16% take AP Biology, 6% take AP Chemistry, and 4 % take AP Physics) (Britner & Pajares, 2006). Osborne, Simon, and Collins (2003), argue that while the students surveyed felt that science was socially relevant, they found school science to be irrelevant and decontextualized. This finding underscores the disparity between the very theoretical curriculum presented by many teachers and the frontiers of scientific discovery that students perceive as happening in the "real world." This apparent disconnect leads to Osborne, Simon, and Collins's (2003) conclusion that, in order to keep students engaged, "school science needs to be less retrospective and more prospective" (p. 15). These findings underscore the importance of addressing students' science self-efficacy beliefs and the fostering of positive attitudes when developing both curriculum and instruction.

Holding Students to an Equitable Outcome

For a student to be college-ready in science he or she must be held to an equitable outcome regardless of socioeconomic status, race, gender, or other identifying attributes. Research shows that inequities in science education exist across diverse demographics, and these inequities must be addressed in order to make college readiness attainable for all students. It is worth restating that it is the belief of the authors that all students can meet high expectations for academic performance when they are held to rigorous standards and taught by qualified science teachers. Further, it is believed that high expectations for academic performance can be obtained without catering to the lowest performing students, but by providing a support system that enables all students to reach their potential. Though a standards document cannot directly address all of the many policy issues related to the educational inequities described below, standards can set the stage for students from all backgrounds to succeed by outlining necessary curricular and pedagogical approaches. The section below is split into two parts. First, statistics organized around identifying attributes are discussed in order to demonstrate current inequities in science education. Next, approaches for supporting diverse sets of students in science education are suggested. This section is structured in this way because it is not possible to make recommendations based on discrete identifying attributes such as race, ethnicity, class, gender, religion, sexuality, etc. Students identify with multiple attributes that interact uniquely for each student (Brotman & Moore, 2008).

Inequities in Science Education

In the United States, a child's socioeconomic status plays a significant role in his or her educational outcome. This is especially true in science. In Benchmarking for Success: Ensuring U.S. Students Receive a World-Class Education, the National Governors Association et. al. (2008) reported that the socioeconomic achievement gap in science is bigger in the U.S. than in almost any other country. The 2006 PISA scores showed that out of 30 countries the U.S. ranked fourth in the relative impact socioeconomic background had on students' score in science. While critics may suggest that this gap is due to our country's diverse demographics, the National Governors Association et al. attributes this gap to the education system's lack of equal learning opportunities and poor norms and mechanisms for supporting students (NGA, CCSSO, and Achieve, 2008). With wealth inequality in the U.S. arguably at its highest – the wealthiest 20% of the population holds 84% of wealth and the bottom 40% holds 0.3% of wealth (Norton and Ariely, 2011) – the socioeconomic achievement gap in science demands attention. New standards in science education must recognize that equal learning opportunities for students are not yet realized, and guidance in how to help all students achieve in science must be provided and rooted in research. Furthermore, stakeholders should make certain that standards do not exacerbate this problem by requiring content be taught in a way that is cost prohibitive to a school district (e.g., the use of specific scientific equipment).

The most documented science achievement gap concerns children of ethnic and racial minority status. As the U.S. becomes more diverse, new standards in science should be more inclusive of students' diverse experiences and ways of thinking and being. The PISA 2006 scores in science showed that immigrant students lag behind their native counterparts, and that students who were born outside of the U.S. scored 1.5 years behind native U.S. students, based on the Organization for Economic Co-operation and Development's definition of a school year. In addition, second generation immigrant students did not perform significantly better than first-generation immigrant students (PISA, 2006). This gap should be of growing concern as demographers predict that a majority of U.S. K-12 students will be from minority racial and ethnic groups by 2023 (NGA, CCSSO, and Achieve, 2008). This gap may be linked to the relative lack of diversity in many scientific fields in the U.S. The National Research Council states that scientists are members of specific cultural groups, and that this "has a tendency to exclude the perspectives of groups that have been historically marginalized" (National Research Council, 2010). Researched-based approaches to make science education more inclusive of diverse student populations are necessary in science education reform.

In addition to gender discrepancies in attitudes towards science, a gender discrepancy also exists in student achievement. Despite the growing number of women in some scientific fields, a science gender gap in the U.S. persists. According to scores on the PISA 2009 science assessment, the U.S. had the third largest gender difference in performance of 65 participating countries, with boys outperforming girls (OECD, 2010). Interestingly, data suggest this gender discrepancy is somewhat specific to the U.S. because boys scored significantly higher than girls in only 11 of 65 participating countries. A majority of countries showed that achievement in science is not linked to one gender or the other, and in countries with the strongest performance boys and girls did equally well (OECD, 2010). These results suggest that science education has the potential to be more supportive of women, and that including women may increase the country's overall performance in science.

In addition to achievement gaps, the relative lack of diversity in college science courses suggests that minorities and women hold negative attitudes towards science and therefore do not enroll in these courses at the same rate as their dominant counterparts. While some fields have more diverse demographics than others, the physical sciences lag behind. In 2007 only 3% of physics bachelor's degrees in the U.S. were awarded to African Americans, and only 4% were awarded to Hispanic Americans. Of those degrees, only 21% went to women (American Institute of Physics, 2007). Women and minorities are choosing not to study certain sciences in college, and this may be due to negative attitudes towards science developed from their experiences in K-12 science classrooms. Reforms in science education should be more inclusive of diverse populations in order to close achievement gaps and promote positive attitude shifts so that all students are supported and held to an equitable outcome of achieving college readiness in science.

Inclusive Approaches

The body of research on how to make science education more inclusive is growing and many countries are including researched based approaches in their standards documents. In a review of ten sets of international standards, Achieve Inc. (2010) identified accessibility to science for all student populations and guidance on how to support this philosophy as one of the exemplary features of other countries' standards documents. Below is a review of literature on equity in science education and suggestions for making U.S. science standards inclusive of all students. Four approaches including multiple epistemologies, indigenous scientific knowledge, cultural boarder crossings, and culturally relevant science education are discussed, but the body of research continues to grow and is not limited to these approaches. Rather, they are intended to show an exemplar way of supporting all students to participate and achieve in science in light of their uniqueness.

All people have multiple ways of knowing, or multiple epistemologies, such as logic, intuition, spirituality, or tradition, and they access certain epistemologies in certain contexts. To include more diverse students in participating in science, researchers suggest respecting students' multiple ways of knowing and presenting science as an additional way of knowing. Many students view science teaching as an attempt at assimilation (Aikenhead, 1999), possibly because science is often presented as truth, reality, and a superior way of knowing that invalidates students' native ways of thinking and being. In this way, science education is received as something similar to missionary attempts to convert indigenous peoples to Western belief systems. This makes science uninviting of and unappealing to students who come from cultures that value other epistemologies, such as spirituality or story telling. When science education conflicts with the indigenous norms, values, and beliefs that children develop in their home environments throughout their lives, they find ways to avoid constructing scientific knowledge (Aikenhead, 1999). To include all students in learning science, science should be presented as an additional, rather than a superior, way of knowing. This allows students to hold their belief systems while acquiring a scientific way of knowing, as opposed to putting students' beliefs in conflict with science and thereby preventing meaningful learning. In order to avoid epistemological hegemony, science standards should include approaches for teaching students how to work with their multiple epistemologies, including strengths of certain epistemologies, when to use what epistemology, and how to draw from multiple epistemologies. For example, science is the appropriate epistemology for studying electromagnetic properties, but a student may draw from cultural knowledge and social sciences in designing a project to bring electricity to a rural town in his or her native country. Some suggestions to address multiple epistemologies in a standards document include:

i) provide guidance on how to promote open dialogue and students' self-examination of beliefs (Cobern, 1994);

ii) discuss how imposing epistemological hierarchies excludes diverse students from science; and

iii) be cognizant of rhetoric so as not to create epistemological hierarchy.

Students should learn science and be supported in evaluating for themselves the legitimacy, value, and purposes of their different ways of knowing.

Cultures throughout history have engaged in scientific practices such as making observations, drawing conclusions, and applying findings to increase peoples' well being. For example, much of contemporary medicine is rooted in traditions that can be traced back to early indigenous knowledge. Nevertheless, science taught in classrooms is often Western science. In order to include more diverse students in participating in science, standards should allow for scientific knowledge from non-Western cultures to be incorporated into the science curriculum. This knowledge is called "indigenous scientific knowledge" (Ogawa, 1995 p. 588) and may, for example, include scientific findings from Native American, African, and ancient tribal civilizations. Some indigenous scientific knowledge may fit easily into the science curriculum, such as the medicinal benefits of plants identified by Native Americans and used by pharmaceutical companies today, and other knowledge may be more difficult to incorporate, such as the Mayan calendar or science of ancient Egyptians, which follow different epistemologies. Researchers suggest incorporating indigenous scientific knowledge into the science curriculum, but maintaining a distinction between indigenous scientific knowledge and dominant Western science and discussing their similarities and differences (Snively and Corsiglia, 2001). By showing that science is not a practice of Western white males, diverse students may feel more included in the practice of science. In order to facilitate this, standards documents should not focus on any one particular or historically significant scientist, but rather, require students be exposed to the theories, experiments, ideas and methods that these scientists are associated with.

Differences between home culture and science classroom culture present another challenge to diverse students. For example, a student from a home culture that is non-confrontational, collaborative, and holistic may have difficulty transitioning to a science classroom culture where argumentation is praised, individual success is rewarded, and knowledge is presented as discrete facts. Most students face cultural boarders between home and school science, and researchers have found that students in both developing and industrialized nations find the culture of school science foreign (Aikenhead, 1999). Research has also shown that a student's success in a science course depends on the extent that he or she perceives the science classroom culture to be different from his or her home culture and the assistance he or she receives in making the cultural transition from home to the science classroom (Aikenhead, 1999). Teachers can help ease the cultural boarder crossings of students by incorporating ways of being from the students' home and social environments into the science classroom. For example, Emdin (2010) suggests using elements of hip-hop culture to help students in urban environments learn science. He points out that both science and hip-hop gain legitimacy through consensus of practitioners, develop sense-making theories based on observation, and validate or dispute theories based on evidence (Emdin, 2010). In gender studies, researchers suggest that presenting science as objective and unbiased discourages some students from participation, and that addressing the "role of subjectivity, creativity, and personal expression in science" may engage marginalized groups in doing science (Brotman & Moore, 2008, p. 988). In order for students to be held to an equitable outcome reforms in science education must reduce the foreignness felt by students (Aikenhead, 1999). Science standards may provide examples of how multiple ways of being can be incorporated into the science classroom in order to ease cultural border crossings.

Students are more successful in school science when they see science as being relevant to their lives (Cobern, 1994). However, school science typically reflects experiences from dominant society and may be irrelevant to students whose identities are marginalized (Barton, 1998), which leads to further marginalization. For example, a discussion on home energy consumption with a picture of a suburban home with two parents and two children may seem irrelevant to a student living in inner-city government housing. For students whose identities and experiences are excluded, science education is an attempt, or lack thereof, at memorizing facts that have no purpose, meaning, or utility. To invite more diverse students to participate in science, culturally relevant science education suggests bringing students' life experiences and ways of being into the science classroom. Some suggestions include: 1) ask students to bring examples from their home environments into the science classroom; 2) help students apply science in their home environments; and 3) elicit and build upon intellectual resources developed from students' unique life experiences. An example of culturally relevant science education is demonstrated in Trinidad and Tobago where researchers George (1988, 1992) and Prime (1994) designed technology-based science experiences drawing from students' knowledge of "street science." Instruction was designed to helped students learn science through building on their indigenous intellectual resources derived from their life experiences. Culturally relevant science education requires an understanding of and openness to students' home environments. For this reason it varies from classroom to classroom and student to student. Nevertheless, standards documents can provide examples of culturally relevant teaching and encourage teachers to elicit student ideas, experiences, and intellectual resources.

Providing Students with a Coherent Pathway of Science Education from K-12

The NRC committee charged with writing *A Framework for K-12 Science Education* lays out in detail the concepts, practices and cross cutting themes that students should learn, and provides loose guidelines for when students should learn this specific content. The NRC's Framework (2011) clearly states, "it is built on the notion of learning as a developmental progression" (p. 1-3). The committee goes on to say that the Framework is:

> designed to help children continually build on and revise their knowledge and abilities, starting from their curiosity about what they see around them and their initial conceptions about how the world works. The goal is to guide their knowledge toward a more scientifically based and coherent view of the natural sciences and engineering, as well as of the ways in which they are pursued and their results can be used. (NRC, 2011, p. 1-3)

Despite this, specifics on how to scaffold appropriate content and skills for students throughout the K-12 science system is an area of much debate. The Framework rightfully points out many of the concerns in providing a ridged pathway, instead opting for what they have labeled "Grade Band Endpoints." While these endpoints have the ability to provide sufficient guidance in defining the content and skills students will need to be College Ready, they do not provide enough guidance for stakeholders on *how* the system will support this goal at each step along the way.

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